Weather/Climate Monitoring – Opportunities for Collaboration

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Based on materials developed by John Gross, reviews of Phase III Network monitoring plans and protocols, and discussions with Inventory and Monitoring staff.

1. Motivation for Collaboration

Weather and climate are key drivers of ecosystem structure and function. Universal, underlying motivation for I&M monitoring of weather/climate is to aid in interpreting trends in other vital signs. Weather/climate is one of the basic 12 I&M inventories. All 17 I&M networks with prioritized vital signs have identified climate as a priority need. Other networks are likely to do the same. Given this program-wide need for weather/climate data, there are obvious opportunities and needs for agency-wide collaboration. Collaboration affords standardization and efficiency.

As background, the terms weather and climate are sometimes used interchangeably, but weather and climate differ in temporal perspectives:

Weather – refers to the condition of the atmosphere at a specific point in time or during a short-lived atmospheric event (Burroughs 2003).

Climate – the aggregate of weather conditions for a location or region and can be defined with averages or representative values for weather elements (Gray and Toivola unpubl.).

For brevity reasons, however, the term climate is used hereafter to indicate both short- and long-term observations of atmospheric conditions.

2. Steps to Establishing a Climate Monitoring Program

Procedures for establishing a climate monitoring program can be organized into six basic steps:

1) defining objectives
2) defining requirements – i.e., delineating specific measurement needs (types and scales)
3) evaluating the data and coverage of existing climate stations (also requires identifying existing climate-monitoring programs in parks)

4) where additional stations are necessary, determining cost-effective partnerships with external climate-monitoring programs or developing a customized network of stations
5) evaluating data management requirements
6) implementation (includes development and implementation of protocols)

Objectives are likely to be specific to a park or network, as are specific requirements of a climate-monitoring network. The remaining steps would benefit from common sources of information, standardized procedures, and program-wide agreements with existing, external climate-monitoring programs (s.l., collaboration).

3. Collaboration Opportunities

3.1. Identifying Existing Climate Programs in Parks

Many external programs contribute to climate monitoring in National Parks. There are roughly 12,000 weather stations operated by federal agencies in the U.S. It is highly probably that at least some of the parks within a network contain a weather station belonging to one or more external climate-monitoring program. A list of agency contacts (names of key personnel, sources for climate-station meta-data) for at least the major climate monitoring programs would greatly facilitate identifying climate stations in parks.

<u>Major, external climate-monitoring programs</u>

National Weather Service (NWS) Cooperative Observing Program (NWS-Coop) – ca. 7,000 stations distributed across the lower 48 states. Started in the late 1800's, this program employs manual observation of basic weather elements – air temperature and precipitation. This program is the basis of the nation's surface observing systems. This program relies on observers collecting and reporting 24-hr measures, and for the most part, still employs liquid-filled thermometers, collection tubes for precipitation, and punch-tape precipitation recording instrumentation. Modernization of this program is described below (see NWS-Coop Modernization).

BLM/Interagency, Remote Automated Weather Stations (RAWS) – ca.1,700 stations with ca. 95% of stations located in wildfire-dominated systems in the western U.S. RAWS stations feature automated measurement and data-transmission capabilities. Data from these stations are primarily used by the wildland fire community. Observations include basic weather elements, in addition to measures of 10-hr fuel moisture and temperature, solar radiation, and wind elements.

Natural Resources Conservation Service (NRCS) SNOwpack TELemetry (SNOTEL) – ca. 600 stations located exclusively in the western U.S. at high elevations. The SNOTEL program provides measures of snow pack which are used to forecast and manage water supplies in the western states. Stations are fully automated, and use meteorburst technology for data transmission.

NRCS Snow Survey Sites – ca. 1,600 sites are located primarily in the western US. Snow Survey employs manual recording of snow-pack measures (snow depth, snow-water equivalent) along transects in high elevation sites during winter months.

Automated Surface Observing System (ASOS) – ca. 800 stations (FAA). These are automated stations located at airports, and provide real-time observations of weather. Stations are not located in parks, but may be sufficiently close enough to park lands for characterization of park weather and climate.

NOAA Climate Reference Network (CRN) – 100-170 stations located systematically across the US. CRN stations are fully automated, high-end stations. This network is intended to provide long-term, detailed reference conditions for other networks.

Other Networks:

USGS Clim-Met (Climate Meteorology) - deployed in support of USGS climate-change research objectives.

NRCS SCAN (Soil Climatic Analysis Network) – deployed in support of intensive monitoring of soil. Only ca. 47 stations, located primarily in the eastern US.

USDA Forest Service Avalanche – automated stations used to monitor snow-pack in high elevation areas.

Air Quality Programs – NPS Continuous Ozone and the interagency IMPROVE programs record basic weather elements in addition other program-specific measures.

There are numerous State and Regional Mesonets throughout the U.S. (e.g., State DOTs).

3.2. Evaluating Data of Existing Stations

Given objectives and requirements for climate monitoring, evaluating the quality of data from existing stations is key to determining necessary station enhancements or to determine if a station meets specified needs. Contemporary observer bias or equipment malfunction can be immediately corrected. Problems with historical data can not be fixed, but may influence the decision to include a station in a park's climate network. When dealing with data from an external program, there is an assumption that QA/QC procedures of the program will flag or eliminated problem data. However, experience has shown this not to be the case. Stringent and consistent evaluation of historical data is critical to determine the reliability of existing climate stations. To this end, developing standardized, rigid QC routines for the main sources of historical climate data would be beneficial to all I&M networks.

3.3 Evaluating the Spatial Coverage of Existing Stations

Evaluating the spatial coverage of existing stations is motivated for two primary reasons: 1) to ensure that key environmental regions or facets are monitored; and 2) to identify locations for additional stations to ensure credible interpolation of climatic measures across a park's landscape. Some initial efforts (e.g., CAKN, SODN) have used various methods to explore station-coverage issues. Methods have included GIS-based delineation of environmental facets, and statistical modeling of existing and experimentally supplemented networks. Additionally, analytical methods and expert opinion have been combined to determine station needs across park landscapes. Documenting the approaches employed by various networks and the lessons-learned in these initial efforts would benefit networks starting to evaluate station coverage in their parks.

3.4 Evaluating Monitoring Program Options

When additional climate stations are necessary, stations can be added by forming partnerships with existing climate-monitoring programs or by developing a customized mesonet.

3.4.1. Partnerships with Existing Climate-monitoring Programs

This approach offers many efficiencies. These include capitalizing on existing expertise, standardized data management and QA/QC procedures, and opportunity to contribute to larger-scale programs. However, there are various factors that must be evaluated when pursuing these partnerships:

Most programs require a minimum suite of measures, and have a maximum suite that will be supported. The maximum suite of measures must satisfy the specified requirements for park-based monitoring.

Sighting requirements of programs must be commensurate with the needs of park monitoring. For instance, high-elevation stations are required by the SNOTEL program. If stations are needed in valley bottoms, other external programs would be more appropriate.

The costs associated with participating in programs can vary. External programs have specific equipment needs and maintenance requirements. The types of automated stations currently employed by most programs range from $12-20k. Maintenance can vary between $2-5k per year. Cost-sharing may be possible, where stations are purchased jointly by NPS and other federal or state agencies, and maintenance is covered by the external program. Trade-offs in equipment purchase and maintenance costs, and cost-share opportunities among programs are important when considering partnerships.

Measurement scales vary among different equipment and external programs. Certain sensors of the CRN stations record observations every 2-s, then averages to derive a 5-min observation that is transmitted and recorded. Instrumentation of other programs use different scaling procedures. Ensuring data-quality compatibility among the suite of climate-stations to be used in park's climate-network is important when adding stations to an existing network.

Data management, access, and QA/QC standards can vary among external programs. Standards offered by an external program must be commensurate with those specified for park monitoring.

3.4.2. Customized Climate-monitoring Network

Creating a customized climate-monitoring network has been pursued by several I&M networks. HTLN has installed stationary, high-end climate stations to monitor sites associated with T&E plants, and has contracted with the Missouri State Climate Lab. for data archiving, analysis, and reporting. The NCPN is proposing to deploy micro-climate stations (HOBO sensors/data loggers) in association with upland field plots to monitor fine-scale climate across park's landscapes.

3.4.3 Opportunities For Sharing

Every I&M network has to consider the key factors listed above when evaluating options for adding climate stations to parks. Synthesizing information on external climate-monitoring programs and making this synthesis available to other networks would greatly facilitate consideration of external programs. Similarly, a general synthesis (vendors, costs-benefits of different equipment suites, etc.) of a range of climate-station types would be of considerable value when contemplating customized approaches.

Ideally, initial experiences in evaluating existing stations, external monitoring programs, and in developing customized approaches could be synthesized by networks or cooperating networks. Syntheses could be placed on the Intranet or made available by other means. This sharing of information would greatly assist networks beginning to consider climate monitoring. At a minimum, a list of in-house I&M contacts for specific issues should be assembled and made available to the larger I&M community.

3.5 Data Management

3.5.1 Raw Data Acquisition

Contemporary raw data from climate stations sometimes can be accessed near-real time or within 1-2 mo. of reporting. In many cases, the raw data are readily accessible for only the calendar year, then data are archived. There are three main methods for accessing archived data: 1) public Internet access, FTP access upon request, and Internet access with password requirements. Programs such as SNOTEL provide public access to hourly to daily measures. State or regional climate centers tend to be repositories for NOAA supported climate data. Depending on the regional climate center, raw NWS-Coop data is served via public Internet access. The Western Regional Climate Center (WRCC) is the repository for RAWS and western Coop data. Access to raw data of RAWS stations requires a password that WRCC freely provides. NWS-Coop data can be acquired free of charge, but currently requires requesting data for specific stations and time periods, and subsequent FTP transfer. The NCPN is currently pursuing an agreement with WRCC that will allow password-protected Internet access to raw data for NWS-Coop station data. Given that most western I&M networks will require the same type of data access, an I&M program-wide agreement with WRCC would be more efficient.

3.5.2 Data Ingest and Storage

There are three approaches to long-term recording of climate station data. One is for an I&M network to locally archive all climate-station data. In cases where data are from a variety of sources, this may require a network having to perform in-house pre-processing and QA/QC. Experience has shown that not all external programs offer QA/QC of raw data. Also, data formats are sometimes confusing, and require pre-processing to better organize the data for local storage. Archiving data locally affords easy access in the future, and ensures that historical data are preserved. The down-side to this approach is the continual increase in storage needs over time. The sharing of data storage approaches and database structures among networks would facilitate standardization and efficiency.

Relying on repositories for raw-data access is more efficient. Where necessary, agreements with repositories can ensure standardized QA/QC and data format for all data sets relevant to a park or network. Long-term access, however, must be assured. Additionally, changes to historical data stemming from improved QC assessments must be communicated to I&M networks. This is necessary to ensure that previous analyses with historical data no longer considered of high quality are discarded or performed with the updated data. Where multiple networks rely on repositories for long-term data access, a program-wide agreement with each repository would be more practical than network-specific agreements.

A third method for long-term recording of climate data would be a centralized database maintained by WASO or a host network. This would offer savings in terms of database design. Additionally, where adjacent networks required data from similar stations, centralized storage would eliminate redundant data storage. WASO has explored this approach, but currently there is a lack of wide-spread support. This may change in the future as networks begin to use climate-station data for various analysis and reporting requirement.

3.5.3 Data Analysis and Reporting

Standard data analysis and reporting would greatly facilitate cross-park, cross-network comparisons of climatic trends. Monthly and annual summaries are fairly standard; the climate reports developed by HTLN are good examples that can be easily implemented by networks. Advanced analyses, however, require specialized experience and knowledge. For instance, climate extremes or deviations from climatic norms are routine options provided by state and regional climate centers. Adapting these routines to climate stations within parks could be accomplished by climate experts within the I&M program, or through contracts with climate centers. Developing a centralized source of advanced analyses would greatly aid networks that lack expertise in climate analyses, and facilitate reporting standardization among networks.

Quality-control procedures are important when aggregating data among climate-monitoring programs. Data from different programs are typically recorded or reported at different temporal scales. Additionally, precision typically varies among programs. Standardized procedures and data-quality checks for scaling data to a common time interval (e.g., scaling from 5-min to 24-hr measures) are used by NWS and other programs involved in climate analysis (e.g., MesoWest). Documenting procedures and making them available to the I&M community would provide standardized methods and foster credible results when analyzing aggregate data sets.

3.6 National Initiatives and Collaboration Opportunities

Two national initiatives have direct relevance to I&M climate-monitoring – NWS-Coop Modernization and the National Climatic Data Center (NCDC) Integrated Surface Observing System (ISOS).

3.6.1. NWS-Coop Modernization

The NWS-Coop modernization program is a recent initiative of NWS. The goal of this program is to fill gaps in the coverage of the existing NWS-Coop network, to increase snowfall density and reporting coverage, to improve forecast accuracy, and to improve data availability. This program will be guided by a network spatial density study conducted to identify weather climate requirements of NOAA, its federal partners, and customers. This program is to be implemented in two phases. The first phase will consist of the network spatial density study that will identify data holes and data-quality issues using a 20 x 20 mile grid scheme across the U.S. The second part of this first phase is the identification of stations with substandard temperature and precipitation sensors, and the upgrading of these sensors (replacing liquid-filled thermometers with electronic sensors, replacing punch-tape precipitation gauges with electronic gauges). Phase II involves the deployment of fully automated stations. About 8-9 thousand stations will be deployed, replacing some existing, manual stations. The modernized stations will feature:

- Hourly temperature and precipitation data (0.01-in resolution)
- Daily snowfall and snow depth

- Measures of soil temperature and moisture, relative humidity, and evaporation in agriculture sensitive areas in support of UDSA's requirements
- Electronic data communications, archiving, dissemination
- Standardized QA/QC
- Near-real time access to temperature and precipitation data

This is a grand opportunity for the I&M program to influence, as much as possible, the upgrading of sensors and stations on park lands. Efforts should be directed at communicating opportunities and needs of NPS with NWS.

3.6.2. ISOS

ISOS is an attempt by NCDC to build a major climate information system that would provide a single, integrated system for data maintenance, data ingest, QA/QC, and data delivery. This system will archive data from the major federal, state, and local climate-monitoring programs, offer standardized QA/QC and data-integration, and provide public access to all raw data and to data passing QA/QC procedures. In support of immediate needs, NWS-Coop, CRN, and ASOS data are first to be integrated into ISOS. This will be followed by integration of data from other federal programs, then data from state and local mesonets.

This is another great opportunity for I&M to benefit from an ongoing national initiative. Communicating to NCDC the opportunities and needs of the I&M program will ensure that I&M is recognized as a major user of the ISOS system. This may contribute to the direction and structure of ISOS. At a minimum, it will ensure that I&M will be positioned to receive some of the dividends afforded by ISOS.

As a cautionay note, the full potential of ISOS will not be realized for some time. The most recent published schedule indicates that the integration of NWS-Coop data into ISOS is planned for FY04-06. All other NOAA surface observing systems (SOS) will be integrated into ISOS in FY07-11. Integration of other federal SOS (e.g., RAWS, SNOTEL) will not begin until data from NOAA programs are fully integrated.

3.7. Implementation

Development of protocols and standard operating procedures (SOPs) must be completed prior to implementation. External monitoring programs already have well established SOPs that can be duplicated or easily modified to meet NPS standards. As protocols and SOPs in NPS standards are created by networks, they should be posted in the WASO protocol database for use by other networks.

3.8. Collaboration with NOAA/NCDC

A meeting between NCDC and WASO (specifically John Gross and Steve Fancy) in late 2004 initiated the development of a Memorandum of Understanding (MOU) between NPS and NCDC. This MOU is under development. The scope of this MOU is unclear at this time, but the intent is to use this MOU to begin to address some of the needs outlined in this presentation. Of special interest is providing program-wide access to data from relevant external climate-monitoring programs, and assistance with QA/QC, data analysis and reporting. As this MOU develops, networks should have the opportunity for input to ensure useful benefits to the every network in the I&M program.

Literature Cited

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Gray, S. and A. Toivola. Unpubl. Detailed study Plan: Development of climate monitoring protocols for the Greater Yellowstone Network.